SP222 Electricity and Magnetism
RC Circuits and Addition of Capacitance

For the check of Capacitance addition rules, repeat the measurements on a single capacitor N times to generate and accuracy estimate due to scatter.

Purpose To study the charging and discharging of the capacitor in an RC circuit, and to verify the rules for computing the effective capacitance of combinations of capacitors.

Reference Tipler, Physics (4th edition)

Introduction A "series RC circuit" consists of a resistor R, a capacitor C, and a source of emf $\mathcal{E}$ connected together as shown in Fig. 1. The switch S permits the capacitor to be either "charged" (when it is in the position labeled 1) or "discharged" (when it is in position 2).

The current I through the resistor and the charge Q on the capacitor both change with time as the capacitor charges or discharges. For example, if the capacitor is uncharged when the switch is placed in position 1 at time $t = 0$, the charge on it at any later time is given by:

$$Q(t) = Q_f\,(1 - e^{-t/\tau}),$$

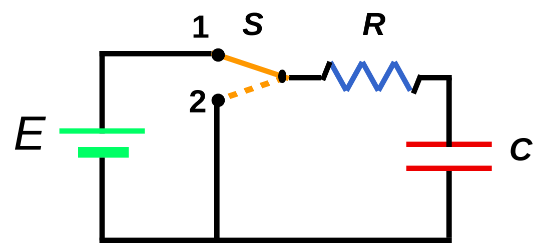


Fig. 1. Series RC Circuit

where $Q_f = \mathcal{E}\,C$ and $\tau = RC$, the "time constant" for this RC circuit. The current through the resistor is related to the charge on the capacitor by $I = dQ/dt$; thus,

$$I(t) = I_0\, e^{-t/\tau},$$

where $I_0 = E/R$.

On the other hand, if the capacitor already has a charge Q_0 on it when the switch is placed in position 2 at time $t = 0$, the charge on it at any later time is given by:

$$Q(t) = Q_0\, e^{-t/\tau}.$$

The current through the resistor is once more given by the expression:

$$I(t) = I_0\, e^{-t/\tau},$$

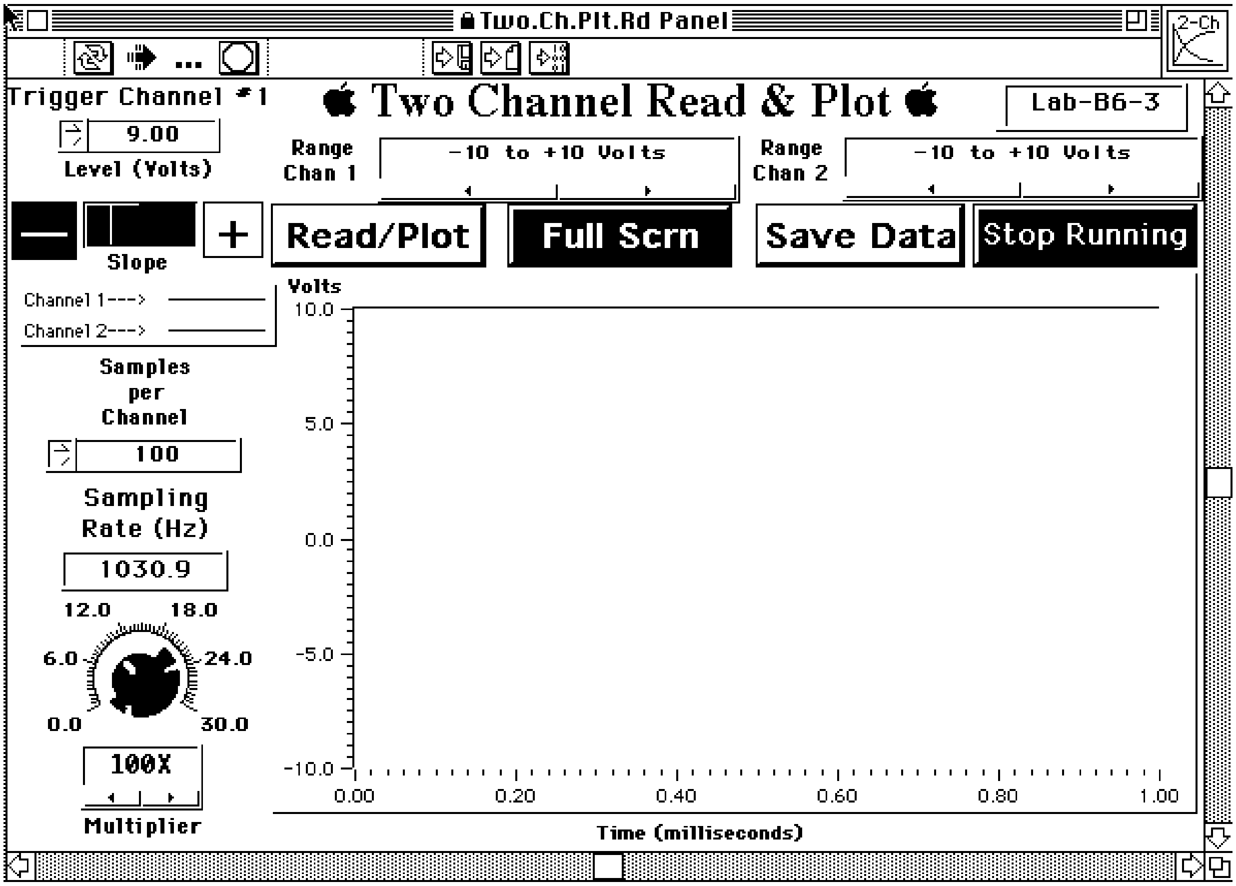
but, in this case, $I_0 = Q_0 / RC$.

You will attempt to verify these predictions. However, the apparatus you will use cannot measure charge or current—it can only measure voltages. This poses no real problem, because the charge on the capacitor is related to the voltage across it by Q = CV, and the current through the resistor is related to the voltage across it by I = V/R, so the desired charge and current may be easily deduced from the measured voltages.

Procedure

Part I. Setup

(1) On the USNA Physics Laboratories screen Click on Two Chan Plot&Read.



This Labview "instrument" will allow you to measure voltage vs. time using Channels 1 and 2 on the USNA Physics Department Interface Box. The following are some hints concerning its operation:

a. Clicking on the button labeled Read/Plot will "arm" the software, preparing it to take data, but measurements will not actually begin until a "trigger" condition, measured on the channel with the lowest number, is satisfied. A "trigger" is a specified combination of voltage and slope—"positive slope" means the measured voltage is increasing with time, and "negative slope" means it is decreasing. The trigger condition is set up using the Level (Volts) and Slope controls located in the upper left-hand corner of the screen. Since you will be using the voltage across the capacitor as the trigger, you must specify positive (+) Slope when charging the capacitor and negative (-) Slope when discharging it. When charging, choose a trigger Level of about 0.05 V, and when discharging, about 9 V.

b. There are four selectable voltages ranges; a choice of -10 to +10 Volts is appropriate for this experiment.

c. The number of data points to be measured may be entered in the window marked Samples per Channel, and the rate at which data is sampled may be set in the range from 3 to 30000 Hz by adjusting the knob under Sampling Rate (Hz) and the Multiplier control. The selected sampling rate will be displayed in the window above the adjustment knob. For this experiment, 100 Samples per Channel and a Sampling Rate of about 1000 Hz are appropriate.

d. Clicking on the button labeled Save Data saves the data to a text file. The first column in the file is time in milliseconds, the second isbe the voltage on channel #1, and the third is the voltage on Channel #2.

(2) Open Data.Editor now as well. Then you can switch back and forth between Two Chan Plot&Read and Data.Editor whenever you want with the pull-down Window menu.

Part II. Discharging a capacitor.

(1) Wire the circuit shown in Figure 2 on the last page of this writeup. Use the Hewlett-Packard DC power supply for the emf E , a resistance substitution box for the resistor R, and a capacitance substitution box for the capacitor C. Choose $E = 10\ V$, $R = 100\ k\Omega$, and $C = 0.5\ \mu F$. What is the time constant for this circuit?

(2) Charge the capacitor by setting the switch S to position 1 and leaving it there for a moment. Check that the trigger is set for a Level of about 9 V and negative Slope. Click on the Read/Plot button, and quickly but smoothly move the switch from position 1 to position 2. In just a moment, plots of the voltages across the capacitor and resistor should appear on the screen. If they do not appear after 10 seconds or so, the Two Chan Plot&Read software probably did not trigger. Check the trigger settings and the connections, reset the switch, and try again.

(3) Once you have good data, save it in a file Include the value of the capacitance in the filename ("Discharging 0.5 uF") so you'll know which data is which later.

(4) Switch to Data.Editor. Read in the file you just saved. Convert the measured voltage across the capacitor (Channel #1, stored in Column b) to values of charge on the capacitor by multiplying by the capacitance C. Make a plot of *ln(charge) vs time*, and fit a straight line to it. What is the physical significance of the slope of this straight line? Does the slope have the numerical value you expected?

(5) Convert the measured voltage across the resistor (Channel #2, stored in Column c) to values of current through the resistor by dividing by the resistance R. Use Data.Editor's integration function ($\int$ y dx) to find the charge that flowed through the resistor during the time spanned by your measurement. Compare the numerical result with the difference between the charge $Q_0 = CE$ that was originally stored on the capacitor and the charge you calculate remains after the time spanned by your measurement.

Part III. Combinations of capacitors.

(1) Remove the capacitance substitution box from the circuit and replace it with a <u>different</u> capacitance substitution box set for $C = 1.0\ \mu F$. Leave $R = 100\ k\Omega$. Obtain data for the discharge of this capacitor, and save the data in a file with a characteristic name ("Discharging 1.0 uF"). Switch to Data.Editor, plot *ln(charge) vs. time* for this capacitor, fit a straight line, and deduce the time constant.

(2) Wire the two capacitance boxes, still set for 0.5 µF and 1.0 µF, in parallel. Obtain data for the discharge of this parallel combination of capacitors. Save ("Discharging parallel"), convert, and plot the data to obtain the time constant. Show that the equivalent capacitance of this combination has the expected value.

(3) Repeat step (2), with the two capacitance boxes wired in series instead of parallel.

Part IV. Charging a capacitor.

(1) Remove the 1.0 µF capacitance box, leaving the 0.5 µF box in the circuit. Discharge the capacitor by setting the switch S to position 2 and leaving it there for a moment. Check that the trigger is set for a Level of about 0.05 V and positive Slope. Click on the Read/Plot button, and quickly but smoothly move the switch from position 2 to position 1. Save the data.

(2) Switch to Data.Editor. Read in the file you just saved. Make a plot of $ln(1 - V/E)$ vs. time, where V represents the voltage across the capacitor at any time and $\mathcal{E}$ represents the power-supply voltage. Fit a straight line to the data. What is the physical significance of the slope of this straight line? Does the slope have the numerical value you expected?

Figure 2. Practical Implementation of Series RC Circuit